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(54) Optoelectronic Microsystem

(57) The invention relates to an optoelectronic element wherein the variation of the optical properties is thermally induced, the temperature variation being effected either by ohmic heat dissipation in the layer structure proper or in a second layer in intimate thermal contact with the first. Further exemplary embodiments are described and sketched in the Figures of the Drawings.

[Figure]

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The information below is taken from the documents provided by the applicant

## Specification

The invention relates to an optoelectronic microsystem according to the preamble of Claim 1.

It is known that the optical properties—in particular the refractive index—of dielectric or semiconducting thin films vary with the temperature. In the case of interference filters, for example, this has the consequence that the wavelength of maximum transmission is dependent on the temperature. This effect is most commonly undesired and as a rule requires costly temperature stabilization.

The production of thin-film membranes on silicon substrates is known from *Mikromechanik* [Micromechanics], edited by A. Heuberger, Springer-Verlag, Berlin, 1989, p. 226 and p. 387. Because of their low heat capacity, such membranes can be rapidly heated to high temperatures at low powers using resistances likewise deposited as thin films. After the heating power is cut off, they again cool down almost equally rapidly by giving up heat to the air surrounding the membrane. For example, silicon nitride membranes of area roughly  $10 \text{ mm}^2$  can be held at approximately  $500^\circ\text{C}$  with a heating power of approximately 120 mW. The heating and cooling time here lies in the range of milliseconds.

It is an object of the present invention to create an optical microsystem of the kind stated at the outset such that the optical properties of one or a plurality of layers can be thermally varied in controlled fashion.

This object is achieved with the practices indicated in Claim 1. Developments and embodiments are stated in the dependent Claims, and exemplary embodiments are explained in the subsequent specification and illustrated in the Figures of the Drawings, in which:

FIG. 1 is a section through a heatable Fabry-Perot interference filter;

FIG. 1b is a diagram of the expected transmission characteristic at room temperature and a temperature of  $500^\circ\text{C}$  for filters with transmission wavelength 500 nm and 1000 nm respectively;

FIG. 2 is a cross section through a silicon membrane according to the prior art;

FIG. 3 is a cross section through a phase modulator with a frequency tuning element;

FIG. 4a is a cross section through a bandpass filter of variable width or, equivalently, as a spectrometer;

FIG. 4b is a diagram of the theoretical transmission behavior of the bandpass filter of FIG. 4a;

FIG. 5 is an overhead view of a membrane having tunable reflection layers with a Gaussian profile.

The combination of optical thin-film deposited structures with heatable membrane elements leads to miniaturized optical components, producible in a batch process, having thermally adjustable spectral properties, which can be operated at frequencies in the kilohertz range. With regard to the achievement of the stated object, it is advantageous that the system—with an eye to attaining fast response times—can be miniaturized and can be produced in a batch process in a fashion compatible with silicon technology.

The general inventive idea provides that the stated object is achieved through the combination of membranes (FIG. 1) with heating elements and optical deposited film structures, wherein the multiple function of layers as membrane layer and/or heating layer and/or optical layer is preserved. To this end, the individual layers with their properties must be selected in controlled fashion and tuned to one another. In particular, the optical layers must be etch-resistant or be passivated, for example with

SiN, in order that etching can be performed as the last processing step in the sense of simple batch processing. Similarly, properties such as optical transmission, high thermal conductivity, low heat capacity for high tuning rates, low remanent mechanical stress and high chemical etch resistance must be kept in view. As a result of the practices according to the invention, a multiplicity of potential applications, which could be implemented only with difficulty or not at all by other methods, are realized in relatively simple fashion.

In the exemplary embodiment sketched in FIG. 1a, a membrane of SiN—which can be produced in an anisotropic, wet-chemical etching process (FIG. 2)—is employed as substrate for a heating element, comprising a meander stripe of platinum, as a multilayer interference filter. In the exemplary embodiment depicted, this multilayer interference filter comprises two reflective deposited film structures that enclose a  $\lambda/2$ <sup>1</sup> layer of hydrogen-containing amorphous silicon (a-Si:H). The reflective layers each comprise  $5\lambda/4$ <sup>2</sup> layer pairs of silicon nitride (SiN) and a-Si:H. In principle, all dielectric films common in interference filter technology can be employed for the production of filters on the membranes. The crucial point for the choice of layer materials is a discontinuity in refractive index between adjoining layers in order to generate the multiple interference, as well as a sufficient dependence of the refractive index on the temperature so that the interference properties can be modified. The arrangement proposed by way of example, of alternating layers of SiN with a-

Si:H, additionally has the advantage of compensating remanent material stresses, because amorphous silicon is usually in compression while silicon nitride layers are usually under tensile stress, so that the remanent stresses largely equalize one another. Any residual stresses that remain are equalized in controlled fashion by additional layers with no optical function. Any arbitrary filter structure, ranging according to the layer sequence and layer material from the single-layer “cutoff” or “cutoff, cuton” interference filter all the way up to narrow-band interference bandpass filters, can be implemented.

In the exemplary embodiment illustrated, the temperature of the interference filter is adjusted in controlled fashion by varying the temperature of the interference filter using the heating element, which is made up either as a meander stripe of vapor-deposited or precipitated platinum, polysilicon or indium tin oxide or another electrically conductive material or is arranged, for example, also as an optically transparent but electrically conductive medium (e.g., ITO) in areal fashion onto or under the filter packet. What is more, by measuring the resistance of the heating element, which likewise depends on the temperature, an item of information about the instantaneous temperature of the heating element and thus also of the filter is also acquired. As a consequence, the filter edge of the multilayer filter is shifted in controlled fashion toward higher or lower temperatures (depending on the fashioning of the filter), and in this way a tunable filter action is obtained.

FIG. 1b shows two transmission curves for the interference filter geometry described above, at room temperature and at 500 °C. The thermo-optic coefficient of a-Si:H is about  $5 \cdot 10^{-4} \text{ K}^{-1}$ , which, for a transmission wavelength of approximately 500 nm or 1000 nm, respectively, leads to a

<sup>1</sup> Thus in the original, possibly an error for  $\lambda/2$ .—Translator.

<sup>2</sup> Thus in the original, possibly an error for  $5\lambda/4$  (i.e., five layer pairs of quarter-wavelength thickness) or for  $5\lambda/4$  (i.e., layer pairs  $5/4$  wavelength thick).—Translator.

shift of approximately 60-80 nm in the center wavelength of the passband. By combining two or a plurality of such thermally adjustable interference filters, a spectrometer can be implemented in which the center wavelength or edge wavelength of the dielectric layers can be modified by adjusting the temperature. Such a spectrometer can be implemented for example as a Fabry-Perot spectrometer at resonance or simply as a system of filters tunable with respect to one another.

FIG. 3 illustrates the design of a phase modulator or frequency tuning element for service in miniaturized laser resonators. Here the thermally induced modification of refractive index and length of an individual layer or a plurality of layers is employed for influencing the phase or frequency of a laser by modifying the optical length of such a layer inserted into the laser resonator. The crucial point with respect to the modulation range is the layer thickness of the cantilevered layer and the level of the temperature, which is adjustable. The heating layer itself can be transparent (e.g., ITO) or is shaped such that it leaves open a transmission window.

An optical bandpass filter of variable transmission curve width can likewise be implemented (FIG. 4a). Two thermooptically modifiable reflective layer membranes are held at unequal temperature, one membrane being structured as a low-pass filter, the other being structured as a high-pass filter, through which the light passes. Transmission occurs only in the overlap region of the individual curves (FIG. 4b). The overlap region is made larger or smaller by varying the temperature difference, all the way up to complete blockage of the transmission passage.

Not illustrated but likewise capable of implementation is a combination of two thermooptic reflective layer membranes, the shift of the filter edge  $d\lambda/dT$  differing in

sign. The temperature of the two membranes is then also to be chosen equal, the width of the overlap region then being a function of the common temperature.

In the same way, a spectrometer can be implemented if the  $d\lambda/dT$  of the two reflective layers is equal. A change in temperature then leads to a shift in the center wavelength, the transmission width remaining constant. In principle, all components can be applied both in transmission and also, analogously, in reflection.

FIG. 5 depicts a tunable reflective layer in which a gradient of the reflection coefficient can be adjusted in controlled fashion via the geometric shaping of the heating layer. For example, a heating layer in the shape of a circular arc leads to a radial temperature gradient, which results in a radial refractive index gradient proportional hereto and, as a consequence, reflection gradients or transmission gradients. In this way, for example, mirrors with a radial reflection gradient ("super-Gaussian mirrors") can be made in which the reflection gradient can be adjusted via the temperature of the heating layer. Such mirrors are useful for example in multimode lasers for reducing the transverse mode structure or as a mode aperture.

## Claims

1. An optoelectronic element for microoptical systems having a thin-film structure—deposited on a substrate layer—which, as to its optical properties—such as refractive index, absorption coefficient, bandgap, etc.—is variable as a function of temperature, characterized in that the variation of the optical properties is thermally induced and the temperature variation is effected either by ohmic heat dissipation in the thin-layer structure proper or in a second layer in intimate thermal

contact with the first, the element being miniaturized and produced in a batch process in a fashion compatible with silicon technology, and membranes having heating elements and optical deposited layer structures in a controlled selection and mutual tuning of their properties (optical transmission, high thermal conductivity, low heat capacity, etc.) being combined with one another.

2. The optoelectronic element of Claim 1 characterized in that the thin-layer structure is a sequence of  $\lambda/4$ <sup>3</sup> or  $\lambda/2$  layers with alternately unequal refractive index.

3. The optoelectronic element of Claim 1 characterized in that the thin-layer structure is one or a plurality of layers made up of amorphous silicon a-Si:H or its alloys.

4. The optoelectronic element of Claims 1 to 3 characterized in that the optical layers are etch-resistant or passivated, for example with SiN.

5. The optoelectronic element of Claims 1 to 4 characterized in that the substrate layer of the layer structure is formed from a membrane of SiN, SiO or SiC produced by anisotropic silicon etching.

6. The optoelectronic element of one of Claims 1 to 5 characterized in that layers of platinum, polysilicon or indium tin oxide are deposited for heating.

7. The optoelectronic element of one of Claims 1 to 6 characterized in that the heating layers are shaped such that an optical transmission window is formed in the substrate membrane.

8. The optoelectronic element of one of Claims 1 to 7 characterized in that the heating layers are shaped such that a controlled temperature gradient is generated on the membrane.

9. The optoelectronic element of one of Claims 1 to 8 characterized in that the heating element is formed from an optically transparent, electrically conductive medium and is arranged in areal fashion on or under the filter packet for the controlled adjustment of the temperature.

10. The optoelectronic element of one of Claims 1 to 9 characterized in that an optical bandpass filter of variable transmission curve width is formed from two thermooptically modifiable reflective layer membranes that are held at unequal temperature and the overlap region can be made larger or smaller by varying the temperature difference of the reflective layer membranes.

Attached: 4 page(s) of Drawings

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<sup>3</sup> Thus in the original, possibly an error for  $\lambda/4$ .—Translator.

## Translation of callouts in the Drawings

### Cover sheet

Interferenzschichten	Interference layers
Pt-Heizschicht	Pt heating layer

### Header on each page of Drawings

Zeichnungen Seite 1 (etc.)	Drawings, page 1 (etc.)
Nummer:	Number:
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### FIG. 1a

Interferenzschichten	Interference layers
Pt-Heizschicht	Pt heating layer

### FIG. 1b

Transmission	Transmission
Wellenlänge [nm]	Wavelength, nm
Raumtemperatur	Room temperature

### FIG. 3

Pt-Heizschicht	Pt heating layer
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### FIG. 4a

Filter 1	Filter 1
Filter 2	Filter 2
thermooptische Beschichtung	Thermooptic coating

### FIG. 4b

Transmission	Transmission
Wellenlänge [nm]	Wavelength, nm
Filter 1	Filter 1
Filter 2	Filter 2
Gesamttransmissionskurve	Net transmission curve

### FIG. 5

Si-Membrane	Si membrane
Pt-Heizschicht	Pt heating layer
Si-Rahmen	Si frame